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Solar energy in India: Strategies, policies, perspectives and future potential

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ABSTRACT

Renewable energy sources and technologies have potential to provide solutions to the longstanding energy problems being faced by the developing countries like India. Solar energy can be an important part of India's plan not only to add new capacity but also to increase energy security, address environmental concerns, and lead the massive market for renewable energy. Solar thermal electricity (STE) also known as concentrating solar power (CSP) are emerging renewable energy technologies and can be developed as future potential option for electricity generation in India. In this paper, efforts have been made to summarize the availability, current status, strategies, perspectives, promotion policies, major achievements and future potential of solar energy options in India.

Contents

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Table 1
Grid-connected renewable power generation capacity in MW (As 30 June 2011).

Renewable energy program	Target for 2011–2012	Total achievement during 2011–2012	Cumulative achievement up to 30.06.2011
Wind energy	2400	394.68	14550.68
Small hydro power	350	63.00	3105.63
Biomass power	460	48.00	1045.10
Bagasse cogeneration		75.00	1742.53
Waste to power (Urban & Industrial)	25	–	19.00
		–	53.46
Solar power	**200**	**2.00**	**39.66**
Total	3435	300.03	20556.05

Source: Ministry of New and Renewable Energy Source India.

1. Introduction

Power sector is one of the key sectors contributing significantly to the growth of country's economy. Power sector needs a more useful role to be played in defining, formulating and implementing the research projects with close involvement of all utilities such that the benefit reaches the ultimate consumer [1]. During the nineties decade, many electric utilities throughout the world have forced to change their way of operation and business, from vertically integrated mechanism to open market system. The increase in energy consumption, particularly in the past several decades, has raised fears of exhausting the globes reserves of petroleum and other resources in the future. The huge consumption of fossil fuels has caused visible damage to the environment in various forms. Every year human activity dumps roughly 8 billion metric tonnes of carbon into the atmosphere, 6.5 billion tonnes from fossil fuels and 1.5 billion from deforestation [2]. India also has followed the global change in power sector by establishment of the Regulatory Commissions in 1998 under the Electricity Regulatory Commissions Act 1998 (Central Law) to promote competition, efficiency and economy in the activities of the electricity industry and applied restructuring to Orissa state electricity board firstly and after that to many other states [3].

India's need to increase energy provision for its population and fast growing economy poses a formidable challenge which is perceived as both a great opportunity as well as a necessity for the country to increase the share of renewables in the overall energy mix. At present India is sixth largest country in the world in electricity generation, having aggregate capacity of 177 GWs out of which 65% is from thermal, 21% from hydro, 3% from nuclear and the rest about 11% is from renewable energy sources [4]. Although Over the years, Indian power sector has experienced a five-time increased in its installed capacity—a jump from 30,000 MW in 1981 to over 176,990.40 MW [4] by 30 June 2011 but still there is a huge gap in generation and demand in India hence need to be establish more generation plants preferably to be come from renewable sources by governmental as well as various private participation.

Electricity generation from renewable is assuming increasing importance in the context of large negative environmental externalities caused by electricity generation from fossil fuels based energy. Managing environmental and its social impacts have been drawing considerable attention in policy-making, project development, and operations [5]. There is increasing environmental concern about the contribution of coal-fired power generation to air emissions, mainly due to the poor quality of Indian coal with an average ash content of 40% or high ash content. Indian coal based generation also coupled with low conversion efficiencies. The 33% of coal based plants generates large amounts of ash with other environmental harmful emission of gases such as carbon dioxide (CO_2), sulphur dioxide (SO_2), and nitrogen oxides (NOx). The future economic development trajectory is likely to result in rapid and accelerated growth in energy demand and the growing energy consumption from conventional sources of energy is likely to leads increasing emissions of gases, compounding the pollution problems and increasing Green House Gas (GHG) emissions [7].

Development of renewable energy sources, which are indigenous and distributed and have low marginal costs of generation, can increase energy security by diversifying supply, reducing import dependence, and mitigating fuel price volatility. Accelerating the use of renewable energy is also indispensable if India is to meet its commitments to reduce its carbon intensity. The power sector contributes nearly half of the country's carbon emissions.

India, total grid-connected renewable power generation capacity of 20,556.05 MW has been achieved till 30 June 2011, which is about 11% of the total installed power generating capacity in the country. It includes wind power of 14,550.6 MW, small hydropower of 3,105.6 MW, biomass power of around 2,787.6 MW, and around 39.6 MW Solar Power as shown in Table 1 [5]. A capacity addition of 14,000 MW is targeted during the 11th Plan period that would take the renewable power generating capacity to nearly 25,000 MW by 2012. This momentum is likely to be sustained and it is envisaged that the renewable power capacity in the country will cross 87,000 MW by 2022.

At the same time there is a need to provide energy access to rural areas and reduce import dependence on fossil fuels. India's approach is to meet its energy needs in a responsible, sustainable and eco-friendly manner. The National Action Plan on Climate Change (NAPCC) in June 2008 identified the development of solar energy technologies in the country was to be pursued as a National Mission. In November 2009, the Government of India approved the "Jawaharlal Nehru National Solar Mission" (JNNSM). The Mission aims at development and deployment of solar energy technologies in the country to achieve parity with grid power tariff by 2022 [6]. The role of solar energy sources has been increasing significantly in recent years due to growing energy demand with minimum environmental impact. Solar energy is clean, safe, easy to maintain and sustainable method of generating power.

The solar photovoltaic is a very important power source for meeting rural electricity demand in this region of the country. Thermal energy is required to fulfill several purposes in the domestic, agricultural, industrial, and commercial sectors of the economy. India is growing towards huge solar energy day by day. As of June 2011, solar power in India had reached a cumulative generation capacity of approximately 39.6 MW. This is approximately 0.002% of JNNSM's 2022 target of 22 GW [5]. While this will be implemented in three stages, the first stage would involve setting up 1100 MW of grid solar power and 200 MW capacities of off-grid solar applications utilizing both solar thermal and photovoltaic technologies, by March 2013 [14].

In present scenario, the solar energy based power generating systems can play a major role towards the fulfillment of energy requirements of industries. The organization of this paper follows the availability, current status, strategies, perspectives, promotion policies, major achievements and future potential of solar energy options in India along with the concluded remark.

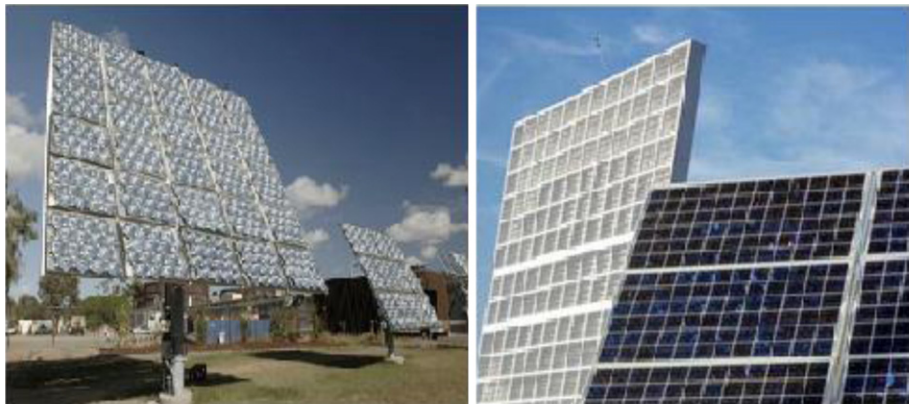


Fig. 1. Concentrating photovoltaic systems [2].

2. Solar thermal power plants

Solar thermal power plants (STE) produce electricity in much the same way as conventional power stations. STE to generate bulk electricity is one of the technologies best suited to helping to mitigate climate change in an affordable way, as well as reducing the consumption of fossil fuels and its produce electric power by converting the sun's energy into high temperature heat using various mirror or lens configurations [11]. STE plants are considered to have a minimum life of 20 years. According to some estimates, India can have a STE installed base of 4–5 GW by 2020. A large amount of Indian STE output is consumed in Delhi, Haryana, and Punjab, drawing upon supply sites in both Rajasthan and Jammu and Kashmir. Population centers in Gujarat are also well positioned to extract power from Rajasthan [12].

3. Concentrating photovoltaic (CPV)

CPV systems have been under development since the 1970s. CPV is another new method of electricity generation from the sun, its employ sunlight concentrated onto photovoltaic surfaces for the purpose of electrical power production (Fig. 1). Solar concentrators of all varieties may be used, and these are often mounted on a solar tracker in order to keep the focal point upon the cell as the sun moves across the sky. CPV plants provide power by focusing solar radiation onto a photovoltaic module, which converts the radiation directly to electricity [11]. These solar cells are typically more expensive than conventional cells used for flat-plate photovoltaic systems. Either mirrors or lenses can be used to concentrate the solar energy for a CPV system. This development has included single axis tracking, line focus CPV and two axis tracking, point focus CPV. Recent development has primarily been on the two-axis tracking systems [13].

Concentrated photovoltaic technology will pave the way to meet the goals of the Indian Government's Solar Mission that promotes sustainable growth while addressing India's energy security. It is an integral part of the initiative to respond to the global challenge of climate change. The first phase of the Mission aims to commission 1000 MW of grid-connected solar power projects by 2013. In addition to helping meet these targets in the most efficient manner, concentrated photovoltaic solar power will introduce a new solar technology to India [14].

4. Solar energy status and current scenario in India

Solar energy is the energy derived from the sun through the form of radiation. India is endowed with rich solar energy resource. The average intensity of solar radiation received on India is 200 MW/km square (megawatt per kilometer square) with 250–300 sunny days in a year. Solar is an important, although currently underutilized, energy resource in India with the potential to offer an improved power supply (especially in remote areas) and increase the security of India's energy supply. Solar energy intensity varies geographically with Western Rajasthan receiving the highest annual radiation energy and the north-eastern regions receiving the least. India has a good level of solar radiation, receiving the solar energy equivalent of more than 5000 trillion kWh/year. Depending on the location, the daily incidence ranges from 4 to 7 kWh/m^2, with the hours of sunshine ranging from 2300 to 3200 per year.

The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6000 million GWh of energy per year. Solar radiation levels in different parts of the country are given in Fig. 2. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of Ladakh region, the parts of Andhra Pradesh, Maharashtra, and Madhya Pradesh also receive fairly large amount of radiation as compared to many parts of the

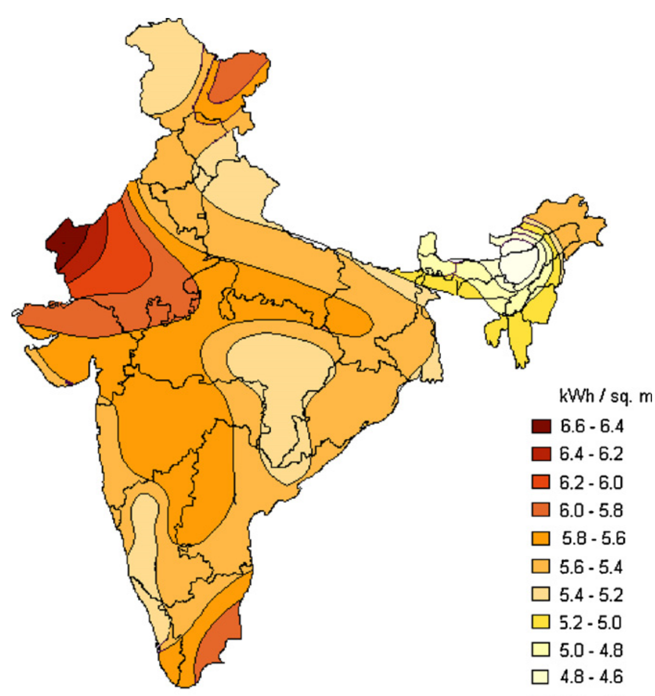


Fig. 2. Solar radiations on India [8].

world especially Japan, Europe and the US where development and deployment of solar technologies is maximum [8].

India's installed solar power capacity of 39.6 MW at the end of June 2010 was based entirely on PV technology with approximately 20% of the capacity being used for off-grid applications [5]. Development of alternate energy has been part of India's strategy for expanding energy supply and meeting decentralized energy needs of the rural sector. The strategy is administered through India's Ministry of New Renewable Energy (MNRE), Energy development agencies in the various States and the Indian Renewable Energy Development Agency Limited (IREDA) [9]. These strategies is being achieved through research and devolvement, demonstration projects, government subsidy programs, and also private sector projects and to promote the maximum utilization of all forms of solar power as well as to increase the share of renewable energy in the Indian market.

A number of solar thermal applications have been developed, which include water/air heating, cooking, drying of agricultural and food products, water purification, detoxification of wastes, cooling and refrigeration, heat for industrial processes, and electric power generation. This technology route also includes solar architecture, which finds utility in designing and construction of energy efficient buildings [5].

In the solar energy sector, some large projects have been proposed, and a 35,000 km^2 area of the Thar Desert (Rajasthan) has been set aside for solar power projects, sufficient to generate 700 GW to 2100 GW. India is ready to launch its Solar Mission under the National Action Plan on Climate Change, with plans to generate 1000 MW of power by 2013. India is planned to generate 1000 MW of solar power every year by 2013. A complete package has been proposed to propel the power sector into 'solar reforms' that could lead to annual production of 20,000 MW by 2020 if phase 1 of the solar mission goes well. The country currently produces less than 5 MW every year.

In the first phase, between 2010 and 2013, the government is also proposing to generate 200 MW of off-grid solar power and cover 7 million m^2 with solar collectors. By the end of the final phase in 2022, the government hopes to produce 20,000 MW of grid-based solar power, 2000 MW of off-grid solar power and cover 20 million m^2 with collectors [10]. The amount of solar energy produced in India is less than 1% of the total energy produced. In India, current grid connected solar power plants in MW peak capacity as shown in Table 2 [5].

North Delhi Power Ltd. (NDPL) has planned a three-fold initiative to promote solar power generation over the next three to four years. It is pursuing the prospect of setting up a 100 MW grid interactive solar power plant in Rajasthan. It will also facilitate grid interactive solar PV systems on the rooftops of individual households and commercial buildings. Gujarat had announced a solar power policy in January 2009, with a target of installing 1000 MW capacities by 2012 and 3000 MW by 2014. The state has already signed power purchase agreements (PPAs) for 934 MW [15].

NDPL consisting of more than 5500 solar photo-voltaic panels designed to produce 1.58 million units of electricity annually, sufficient to light more than 1000 homes on Lawrence Road at Keshavpuram. India is on track to install 1.1 GW of grid-connected

Table 2
India's current grid connected solar power plants (As on 31 July 2011) [4].

S. no.	State	Project developer	Capacity (MWp)	Location	Month of commissioning
1.	Andhra Pradesh	Sri Power Generation (India) Private Limited	2	Varadayapalem Mandal, District: Chittoor, Andhra Pradesh	April, 2011
2.	Delhi	Reliance Industries Limited	1	Thyagaraj Stadium, Delhi	April, 2010
3.		North Delhi Power Limited	1	Keshavpuram, Delhi	December, 2010
4.	Gujarat	Lanco Infratech Limited	5	Charanka Solar Park, District: Patan, Gujarat	January, 2011
5.		Sun Edison	1	Gandhinagar, near PDP Uni.	January, 2011
6.		Azure Power Private Limited	5	Khadoda Village. District: Sabarkhanta, Gujarat	June, 2011
7.	Haryana	C & S Electric Limited	1	Village Nandha, Badhra Mandal, District: Bhiwani, Haryana	June, 2011
8.	Karnataka	Karnataka Power Corporation Limited	3	Yelasandra village, Bangarupet Taluka, Dist: Kolar, Karnataka	Novmber,2009
9.		Karnataka Power Corporation Limited	3	Itnal village, Chikodi Taluka, District: Belgaum, Karnataka	December, 2009
10.	Maharashtra	Maharashtra State Power Generation Corporation Limited	1	Chandrapur STPS, Chandrapur, Maharashtra	April, 2010
11.		Tata Power Company	3	Mulshi, District: Pune, Maharashtra	March, 2011
12.		Dr. Babasaheb Ambedkar Sahkari Sakhar Karkhana Limited	1	Arvindnagar, Keshegaon, Tq. & District: Osmanabad Maharashtra	July, 2011
13.	Orissa	Raajratna Energy Holdings Private Limited	1	Sadeipali, District: Bolangir, Orissa	June, 2011
14.	Punjab	Azure Power Private Limited	2	Village Ahwan, Tehsil Ajanal, District: Amritsar,Punjab	December, 2009
15.	Rajasthan	Reliance Industries Limited, Solar Group	5	Khasra No. 1133, Village Khimsar, Tehsil: Khimsar, District: Nagaur, Rajasthan	July,2010
16.		ACME Tele Power Limited	2.5	Bherukhada, Bikaner, Rajasthan	May, 2011
17.	Tamil Nadu	Sapphire Industrial Infrastructures Private Limited	5	Village Rettai Pillai, Iynarkulam, Taluk New Kallthur Sivaganga, District: Sivanganga, Tamil Nadu	December, 2010
18.		B & G Solar Private Limited	1	Komal WestVillage, Mayiladuthurai, Tami Nadu	June, 2011
19.		R L Clean power Private Limited	1	Marakathoor village, Kalayarkoil Taluk, Sivaganga District, Tamil Nadu	July, 2011
20.	West Bengal	Green Energy Development Corporation Limited	1	Seebpore Power Station of DPSC Ltd., Block Jamuria, Asansol, West Bengal	August, 2009
		Total	**45.5**		

Source: Ministry of New and Renewable Energy Source India.

Table 3
Deployment across the application segments.

S. no.	Application segment	Target for Phase 1 (2010–2013)	Target for Phase 2 (2013–2017)	Target for Phase 3 (2017–2022)
1.	Solar collectors	7 million m^2	15 million m^2	20 million m^2
2.	Off grid solar Applications, including rural solar lights	200 MW	1000 MW	2000 MW
3.	Utility grid power, including roof top	1000–2000 MW	4000–10,000 MW	20,000 MW

solar power by 2013 and is on target to reach its 20 GW goal by 2022. The Indian government has awarded 184 MW of projects that are to be completed by 2011. In addition, bids have been opened for 620 MW of generating capacity, and invitations to bid on an additional 300 MW of capacity will open soon. About 10% of India's installed generation capacity is currently sourced from renewables [16].

India's vision of reducing emission intensity of the economy by 20–25% through utilization of its abundant solar resources and providing 500 GW of clean energy through thorium based nuclear energy by 2050. The NAPCC has presently set a target of 5% of power purchase from renewables, which will be increased by 1% each year to reach 15% by 2020 [16].

The JNNSM Mission will be implemented in three phases, spanning the remaining period of the 11th Plan and first year of the 12th Plan (up to 2012–2013) as Phase 1, the remaining 4 years of the 12th Plan (2013–2017) as Phase 2 and the 13th Plan (2017–2022) as Phase 3. The aspiration is to ensure large-scale deployment of solar generated power for grid connected as well as distributed and decentralized off-grid provision of commercial energy services. The deployment across the application segments is envisaged as follows in Table 3 [17].

5. Off-grid and decentralized solar application

The immediate aim of the JNNSM Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level. These include solar water heating systems, home lighting systems which include solar lanterns, solar cooking systems, solar pumps and small power generating systems. Within the off-grid component, there is a separate target of covering 20 million rural households with solar lights. In Table 4 shown as, solar off-Grids and decentralized energy systems [5].

6. Grid electricity savings by using solar lighting in India [16]

The economics of installed solar photovoltaic street lighting system (in India) has been worked out considering the life of system as 15 years. The AC electrical energy savings by using solar photovoltaic street lighting and home lighting system is presented in Table 5 [16].

Table 4
Achievements in off-grid renewable power and decentralized energy systems [5].

S. no.	Resources/systems	Cumulative achievements (up to 31.01.2011)
Off-grid/distributed renewable power (including captive/CHP plants)		
1.	Biomass power/cogen. (non-bagasse)	282.07 MW
2.	Biomass gasifier	128.16 MWeq
3.	Waste-to-energy	67.99 MWeq
4.	Solar PV Power Plants	4.420 MWp
5.	Aero-Generators/Hybrid Systems	1.12 MW
6.	Watermills/microhydel	10.13 MW (1450 nos)
7.	Total	493.89 MWeq
Decentralized Energy Systems		
1.	Family type biogas plants	4.32 million
2.	SPV home lighting system	6,69,805 nos.
3.	Solar lantern	8,17,549 nos.
4.	SPV street lighting system	1,22,697 nos.
5.	SPV pumps	7495 nos.
6.	Solar water heating – collector area	3.97 million sq. m.
7.	Solar cookers	6.39 lakhs
8.	Remote village electrification	8033 villages and hamlets
9.	Energy parks	514 nos.
10.	Aditya solar shops	302 nos.
11.	Battery operated vehicles	305 nos.

Source: Ministry of New and Renewable Energy Source India.
MWeq. = megawatt equivalent; MWp = megawatt peak; sq. m. = square meter.

7. Government initiatives to promote solar energy in India

There are several electricity policies in the last few years have talked about the need and priority to promote renewable energy. Foremost amongst them is the Electricity Act (2003) which delicensed stand-alone generation and distribution systems in rural areas [18,19]. The National Rural Electrification Policy, 2005 [20] and National Rural Electrification Policy, 2006 also stresses the need for urgent electrification [21]. The New Tariff Policy (2006) stated that a minimum percentage of energy, as specified by the Regulatory Commission, is to be purchased from such sources [22]. The details of directive released by Indian government to promote renewable energy are discussed in later sections.

7.1. Electricity Act 2003

In this act provides that cogeneration and generation of electricity from renewable sources would be promoted by the State Electricity Regulatory Commissions (SERCs) by providing suitable measures for connectivity with grid and sale of electricity to any

Table 5
Grid electricity savings by using solar lighting systems.

Item and no. installed	Energy use/h	Electrical energy required to operate 40 W incandescent lamp to get same lumen intensity (450 lumen) as of 11 W CFL	Savings[a] (Rs./h)	Savings[a] (Rs.)/annum
Solar street lighting system: 20 no.	220 Wh	800 Wh	3.20	9344
Solar home lighting system: Model 1: 02 no.	$2 \times 9 = 18$ Wh	$2 \times 40 = 80$ Wh	0.32	934
Solar home lighting system: Model 2: 05 no.	$5 \times 2 \times 9 = 90$ Wh	$5 \times 2 \times 40 = 400$ Wh	1.6	4672
DC Fan: 07 no.	$7 \times 9 = 63$ Wh	78.75 Wh If AC current is used to operate these fans, 63 Wh/0.80 = 78.75 Wh	0.315	927
Total savings (Rs.)			5.435	15,877

[a] Commercial electricity charge = Rs. 4.0/kWh.

person and also by specifying, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee. Such percentage for purchase of power from these sources should be made applicable for the promotional tariffs to be determined by the SERCs at the earliest. Progressively the share of electricity from renewable energy sources would need to be increased as prescribed by SERCs. Such purchase by distribution companies shall be through competitive bidding process. Considering the fact that it will take some time before renewable technologies compete, in terms of cost, with conventional sources, the commission may determine an appropriate differential in prices to promote these technologies [18].

Moreover with advent of SERCs in various states with restructured power sector every state has set Renewable portfolio obligation (RPO/RPS) in their respective state. With such type RE policy and the corresponding regulatory environment provide a framework for the pricing signals and projected viability and sustainability of renewables. The sections of EA-2003 which emphasis for promotion of renewable in India are give below:

(a) Section 86 (**1**) (**e**)—"The State Commission shall discharge the following functions, namely: promote cogeneration and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total Consumption of electricity in the area of a distribution license".
(b) Section 61 (**h**)—"The Appropriate Commission shall, subject to the provisions of this Act, specify the terms and conditions for the determination of tariff, and in doing so, shall be guided by the following, namely: the promotion of cogeneration and generation of electricity from renewable sources of energy".

7.2. National Electricity Policy 2005

The National Electricity Policy 2005 stipulates that progressively the share of electricity from non-conventional sources would need to be increased; such purchase by distribution companies shall be through competitive bidding process; considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the commission may determine an appropriate deferential in prices to promote these technologies [19].

7.3. National Tariff Policy 2006

As per the National Tariff Policy 2006 the State Electricty Regulatory Commissions (SCRC) to specify a Renewable energy Purchase Obligation (RPO/RPS) by distribution licensees in a time-bound manner. The Policy announced in January 2006 has the important provision for renewable promotion such as in pursuant to provisions of section 86 (**1**) (**e**) of the E' Act 2003, the Appropriate Commission shall fix a minimum percentage for purchase of energy from renewable sources taking into account availability of such resources in the region and its impact on retail tariffs. Such percentages for purchase of energy should be made applicable for the tariffs to be determined by the SERCs. It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, procurement by distribution companies shall be done at preferential tariffs determined by the Appropriate Commission. Such procurement by Distribution Licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the E' Act 2003 within suppliers offering energy from same type of non-conventional sources. In the long-term, these technologies would need to compete with other sources in terms of full costs of generation. The Central Commission should lay down guide lines with in three months of its establishment for pricing nonfarm power, especially from non-conventional sources, to be followed in cases where such procurement is not through competitive bidding [21,22].

7.4. National Rural Electrification Policies (NREP), 2006

The goals of NREP-2006, include provision of access to electricity to all households by the completion of year 2009, quality and reliable power supply at reasonable rates, and minimum lifeline consumption of one unit/household/day as a merit good by year 2012 [17]. For villages/habitations where grid connectivity would not be feasible or not cost effective, off-grid solutions based on stand-alone renewable based systems may be taken up for supply of electricity. Where these also are not feasible and if only alternative is to use isolated lighting technologies like solar photovoltaic, these may be adopted. However, such remote villages may not be designated as electrified. State governments have to be prepared and notify a rural electrification plan in their respective states, which should map and detail the electrification delivery mechanism. The plan may be linked to and integrated with district development plans. The plan should also be intimated to the appropriate commission. Moreover, Gram Panchayat shall involve in it and issue the first certificate at the time of the village becoming eligible for declaration as electrified. Subsequently, the Gram Panchayat shall certify and confirm the electrified status of the village as on 31st March each year [23,24].

7.5. Initiatives to promote solar PV in India

The NREP-2006 policy aims at providing access to electricity to all households in the country and a minimum 'lifeline' level of consumption of 1 unit (kWh) per household per day. The policy also mentions that off-grid solar PV solutions may be deployed where the supply of grid electricity is infeasible. The policy also mentions that off-grid solar PV solutions may be deployed where the supply of grid electricity is infeasible [25].

7.6. Semiconductor Policy (2007)

The Semiconductor Policy is meant to encourage semiconductor and ecosystem manufacturing, of which solar PV is also a component. It offers a capital subsidy of 20% for manufacturing plants in SEZs and 25% for manufacturing plants outside of Special Economic Zones (SEZs). The subsidy is however, based on the condition that the net present value (NPV) of the investment is at least US $212 mn (Rs. 10,000 mn at 1 US$ = Rs. 47) [25].

7.7. Solar PV generation based incentive

MNRE formed guidelines for generation based incentives for grid connected solar (both thermal and PV) plants in January 2008. The scheme was extended to all existing registered companies, Central and State power generation companies and public/private sector PV power project developers. The scheme promoted grid connected power plants in excess of 1 MW of capacity at a single location. The scheme was limited to 5 MW per developer across India and a maximum of 10 MW per state.

According to this scheme, MNRE offered to provide, through IREDA, a generation-based incentive of a maximum of Rs. 12/kWh to eligible projects, which are commissioned by December 31 2009, after taking into account the power purchase rate (per kWh) provided by the State Electricity Regulatory Commission or utility for

that project. Apart from the Central Government, several State Governments have also taken [5,17].

7.8. State level initiatives

The State Electricity Boards and respective agencies for renewable energy at the state level, play a key role in implementation at a state level. Independent of these national efforts, states are promoting solar power. Gujarat, for example, is promoting the installation of 350 MW solar PV by 2011. It offers a feed-in tariff of Rs. 15/kWh for the first 12 years and Rs. 5/kWh for the following 13 years [26]. Prevailing tariffs for solar power across Indian states are shown in Table 6.

7.9. Research & development (R&D) initiatives

For technology development, the R&D strategy would comprise five categories, viz.

- Basic research having a long term perspective for the development of innovative and new materials, processes and applications.
- Applied research aimed at improvement the existing processes, materials and the technology for enhanced performance, durability and cost competitiveness of the systems/ devices.
- Technology validation and demonstration projects aimed at field evaluation of different configurations, including hybrids with conventional power systems for obtaining feedback on performance, operability and costs.
- Development of R&D infrastructure in private public partnership mode, and
- Support for incubation and start ups, a 3-tier R&D institutional framework, including high level research council, National Center of Excellence and a network of centers of excellence.

8. Reduction in environmental pollutions by solar power generation

Renewable energy is central to climate change mitigation efforts and estimates indicate that mitigation from existing renewable energy portfolio is equivalent to around 4–5% of total energy related emissions in the India. Emission of pollutants like CO_2, SO_2, and NOx is highly reduced by installation of CPV systems. Additional bonus

Table 6
Prevailing tariffs for solar power across states in India [26].

State/agency	Order dated	Tariff period	Counter period	Tariff (Rs./kWh)
Chattisgarh	08.09.2008	Levelised for 10 years	08.09.2008 to 31.8.2018	Applicable for plants commissioned up to 31.12.2010 Tariff- Rs. 15.84/kWh Incentives to developer/licensees – Rs. 3.84/kWh
Gujarat	Draft order–23.07.2009	Levelised for 25 years		1–12 years of operation- Rs. 14.0/kWh 13–25 years of operation – Rs. 4.0/kWh
Haryana	25.04.2008			Applicable tariff for solar PV plants only commissioned up to 31.12.2009 – Rs. 15.96/unit 31.12.2010 – Rs. 15.16/unit Generation based incentive from State Government for plants commissioned up to 12.2009 – Rs. 12.00/unit 12.2009 – Rs. 11.40/unit Only net rate after deducting incentive amount shall be payable by distribution companies Tariff to remain constant for period of 5 years
Kerala	Draft regulation 2008–27.08.2008	Levelised tariff for 10 years		Tariff – Rs. 15.18/kWh Developer to provide energy to the distribution companies at Rs. 3.18/kWh (for 10 years) and collect incentive at Rs. 12/kWh from IREDA
Maharashtra	08.05.2009	10 years		Applicable for plants commissioned up to 31.03.2010 and under Generation Based Incentive scheme Tariff under GBI scheme – Rs. 3/kWh Max. incentive to the project developer – Rs. 12/kWh
Rajasthan	Regulation, 2009–23.01.2009	10 years		Total tariff inclusive of generation incentive COD upto 31.12.2009 15.78 31.12.2010 15.18 Applicable for 10 years only PPA can be executed for life of plant
Tamil Nadu	11.07.2008	10 years		Rate for procurement of power by distribution companies: COD up to 31.12.2009 3.15 Max. incentive of Rs. 12/kWh is admissible for COD up to 31.12.2009
Uttar Pradesh	Draft regulation- 09.09.2009	20 years	5 years	For plants covered under MNRE scheme and commissioned up to 31.12.2009, Max, incentive – Rs. 12/kWh Projects commissioned after 31.12.2009 – Rs. 11.40/kWh For plants not covered under GOI incentive scheme- Rs. 15/kWh
Uttarakhand	Draft regulation 2009 – 30.12.2009	20 years	2009–2010 to 2012–2013	For plants commissioned up to 31.03.2010: Rs. 17/kWh

for going solar is elimination of noise and air pollution. The NAPCC includes the main enabler for STE projects in India. The JNNSM targeted of 20 GW of grid-connected solar power to be installed by 2022 (based on both CSP and CPV technologies). This has the advantages of production at consumption points and does away with land and environmental related concerns and problems. India's climate modeling studies show that its per capita emissions will be around 2–2.5 tonnes of carbon-dioxide equivalent by 2020 and around 3–3.5 tonnes of carbon-dioxide equivalent by 2030, compared to around 1–1.2 tonnes presently [27].

In order to reduce carbon emissions from India, the government currently spends over 2.6% of the gross domestic product (GDP) on adaptation to climate variability, with specific areas of concern in agriculture, water resources, forests, health and sanitation, coastal zone infrastructure and extreme events. On average, every 1 GW of additional renewable energy capacity reduces CO_2 emissions by 3.3 million tonnes a year. So there is a great need to promote the CSP in Indian power sector to meet future energy demand and remove GHG emission for environment protection [17]. The NAPCC suggested that as much as 15% of India's energy could come from renewable sources by 2020. Total number of 106 projects accounting solar generations of 40.648 MW have been sanctioned during 2010–2011 under off grid STP application of JNNSM [17]. The MNRE planned to reduce carbon emissions (generated by burning the diesel of generators associated to cell phone towers) by using solar power. India has 250,000 cell phone towers, each of which uses 3–5 kW of power depending on the number of operators using them [28].

9. Dust issues in India with CSP & CPV

Large-scale solar power plants are increasingly landing in desert and arid areas across the India. Dust is a major problem with solar panels in India; CSP and CPV power plants can lose up to 30% energy output within a few weeks of installation. A dust layer decreases solar power conversion 40% by 4 g m^{-2}. Dust is deposited each month at over 4 times that amount. Deposition rates are big issues in India. It is therefore essential to maintain them with regular cleaning; at least every other day. There are automatic cleaning systems like solar wash and others available abroad, but manual cleaning is a far more inexpensive option in India. Cleaning thrice a week and washing once a month is essential in most of the Indian locations [29].

The panels are covered with a transparent screen impregnated with transparent indium tin oxide electrodes. Recently, this technology as developed for mars roving machines allows for the removal of dust by coating the surface of the machine or solar panel with electrodes of Indium tin oxide, it is a transparent, electrically sensitive material and electronic sensors. The sensor monitor dust levels and when they become critically high, it energizes the Indium tin oxide. The electrodes then send sharp cascading electrostatic pulses across the material, and this effectively shakes the dust off. This process can remove 90% of dust in 2 min and requires very little electricity. This may be the best option to remove dust in solar panels, especially in India [30].

10. Major achievements in solar sector

India's major achievements on solar energy development can be summarized as follows:

- 3600 remote villages/hamlets, including those in Sunderbans, Bastar, Ladakh and the North East electrified through solar energy.
- Largest solar–steam cooking system for 15,000 persons/day set up at Tirupati Tirumala Devasthanam.
- 7 lakh m^{-2} collector area solar water heating systems installed.
- 30 MWcapacity Solar Photovoltaic products exported to various developed and developing countries.
- Solar Energy Center set up for development of solar energy systems and devices at Gurgaon in Haryana.
- A new architecture has been designed for the 1000 MW projects.
- The tariff for current year for PV is Rs.17.91 per unit and Rs. 15.31 per unit for solar thermal power. NTPC Vidyut Vyapar Nigam (NVVN) has issued request for selection of new grid power projects of 620 MW capacities. About 450 applications to set up 5000 MW capacities have been received.

11. Future of solar energy in India

India, faced with twin challenges on energy and environmental front, has no option but to work towards increasing the role of renewable in the future energy systems. The objective of the JNNSM is to establish India as a global leader in Solar Energy, by creating the policy conditions for its diffusion across the country as quickly as possible.

- New project developers for 100 MW capacity of grid (below 33 kV) connected solar projects (of 100 kW to 2 MW capacities each) have also been selected. It is expected that 150–200 MW of solar power will be installed in the country by December 2011.
- To create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022.
- To ramp up capacity of grid-connected solar power generation to 1000 MW within three years by 2013; an additional 3000 MW by 2017 through the mandatory use of the renewable purchase obligation by utilities backed with a preferential tariff. This capacity can be more than doubled – reaching 10,000 MW installed power by 2017 or more, based on the enhanced and enabled international finance and technology transfer. The ambitious target for 2022 of 20,000 MW or more, will be dependent on the 'learning' of the first two phases, which if successful, could lead to conditions of grid-competitive solar power. The transition could be appropriately up scaled, based on availability of international finance and technology.
- To create favorable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.
- To promote programs for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022.
- To achieve 15 million m^2 solar thermal collector area by 2017 and 20 million by 2022.
- To deploy 20 million solar lighting systems for rural areas by 2022.
- JNNSM Mission has set a target of 1000 MW by 2017, reaching million households. To meet this target, the Mission plans to provide solar lighting systems to over 10,000 villages and hamlets and also to set up stand alone rural solar power plants in special category States and areas such as Lakshadweep, Andaman & Nicobar Islands and the Ladakh region of Jammu & Kashmir.
- The State Government of Andhra Pradesh is developing a solar farm cluster called solar city on a 10,000 acre land at Kadiri in Anantapur district. Solar city is expected to attract investments worth Rs. 3000 crore in the first phase. Four firms (Sun borne, Lance Solar, AES Solar and Titan Energy) have signed a memorandum of understanding with the State to set up their units there. These companies will be the anchor units in solar city and have a combined capacity of 2000 MW.
- Karnataka Power Corporation Ltd. has implemented two projects – each of 3 MWp capacity and has awarded a third project of same

capacity recently. The solar plants, located in Kola and Chickadee districts, have been implemented under the Arunodaya scheme for ensuring assured power supply to rural areas, especially irrigation pump sets. These PV power plants are intended as tail end support/powering of irrigation pumps.

12. Research and development investment in solar power

A number of major government and industry R&D efforts aim to make STE and CPV a mainstream power source within the next decade. India is each pursuing an aggressive solar energy growth strategy, creating a very important industry and setting up ambitious mid-term targets for the domestic market in the multi-GW scale. The CPV technology is presently moving from pilot facilities to commercial-scale applications. By Eleventh Five-Year Plan (2007–2012) GOI proposed a solar R&D funding of amount Rs. 400 crore. The working group on R&D for the energy sector proposed an additional Rs. 5300 crore in Research, demonstration and development for the eleventh five-year Plan, with the two largest topics being: research on silicon production for PV manufacturing and research on Light emitted diodes [5,31]. India make a global leader in solar energy and the mission envisages an installed solar generation capacity of 20,000 MW by 2020, 100,000 MW by 2030 and of 200,000 MW by 2050. The total expected funding from the government for the 30-year period will run to Rs. 85,000 crore to 105,000 crore [31].

13. Conclusions

India has a severe electricity shortage. It needs massive additions in capacity to meet the demand of its rapidly growing economy. Development of solar energy, which is indigenous and distributed and has low marginal cost of generation, can increase energy security by diversifying supply, reducing import dependence, and mitigating fuel price volatility. Solar energy development in India can also be an important tool for spurring regional economic development, particularly for many underdeveloped states, which have the greatest potential for developing solar power systems which is unlimited and clean source of energy. It can provide secure electricity supply to foster domestic industrial development. So it can be concluded that photovoltaic power systems will have an important share in the electricity of the future not only in India, but all over world.

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